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Green roofs as passive system for energy savings when using rubber crumbs as drainage layer

Gabriel Pérez, Julià Coma, Cristian Solé, Albert Castell, Luisa F. Cabeza

GREA Innovació Concurrent, Universitat de Lleida, Lleida, Spain
Edifici CREA, Universitat de Lleida, Pere de Cabrera s/n, 25001-Lleida (Spain)
Phone: +34-973 003576, Fax: +34-973 003575; e-mail: lcabeza@diei.udl.cat

Abstract

This study is another step of a long-term work in order to study the thermal behaviour of extensive green roofs in dry Mediterranean Continental climate. In this paper there are two main goals. On one hand, the possibility of using rubber crumbs as a drainage layer in green roofs, substituting the porous stone materials used in some commercial solutions is studied. On the other hand, new data concerning the use of green roofs as passive system for energy savings in dry Mediterranean Continental climate is provided. First results correspond to summer 2011, when the roof was just planted and the irrigation system installed. The vegetation cover in those days was about 20% of the roof surface. With an internal set-point of 24 °C first results show an improvement in energy consumption with respect to the reference cubicle. New data will be recorded during 2012 when the vegetation has developed and it is expected better results than in 2011.

Keywords: Green roof; drainage lyer; rubber crumbs; energy savings

1. Introduction

The building envelope is very important to improve performance and energy savings in the building sector. Today, extensive green roofs have been consolidated as a sustainable construction system that offers interesting advantages in this area [1-22].

This research considers both the study of the functional benefits of green roofs and also the goodness of their own construction. The green roof solution evaluated in this research adds a plus of sustainability due to the use of recycled rubber crumbs as drainage layer instead of conventional materials such as expanded clay, pumice, or natural puzolana. On the other hand, the insulation layer has been omitted because it isn't necessary in this system roof. In previous studies, the possibility of using rubber crumbs

* Corresponding author. Tel.: +34-973-00-35-76; fax: +34-793-00-35-75. *E-mail: lcabeza@diei.udl.cat*

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instead of puzolana as drainage layer material in extensive green roofs was confirmed [23]. In addition, first studies about the thermal behaviour of this solution, without plants, started [24]. This system reduces the consumption of natural materials, which also require large amounts of energy in their transformation process. Moreover, this green roof system provides a good thermal behaviour when it compares with one conventional flat roof, with insulation layer.

This paper corresponds to a new step of this research, in which data corresponding to summer 2011 have been analysed. Previous studies were conducted without plants. The main difference compared in previous studies is that planting took place in spring 2011 and now the plants cover a 25% roof surface. Moreover, a simple irrigation system was installed to ensure the survival of plants in the summer months, under Continental Mediterranean climate conditions.

The experiments took place in Puigverd de Lleida, Spain. Lleida has a climate classified as Dry Mediterranean Continental, characterized by its great seasonal variations. It has low rainfall divided in two seasons, spring and autumn, and it has a thermometric regime with large differences between a long winter (between the spring and the last frost may take more than 160 days) and a very hot summer. The average annual rainfall of between 350-550 mm, and the mean annual temperatures oscillates between 12-14 ºC, with thermal amplitudes of 17-20 ºC. A special mention must be made to the fog, typical of the region in the months of November, December and January that can be given a period of up to 55 days in the absence of sunlight. This is a very similar climate to that of the area of Madrid, while taking this more annual rainfall and fewer days of fog per year.

The system used corresponds to an extensive green roof with a drainage layer of 4 cm of natural puzolana directly below to the substrate layer (5 cm thickness) [25]. According to the recommendations given by the company commercializing the reference system used here, between these two layers no filter layer was placed. In this type of climate and for extensive green roofs, irrigation during the summer months is also recommended.

The aim of this paper is to compare thermal behaviour and energy consumption of three identical cubicles where which the only difference lies in the composition of the roof system. Two of them have extensive green roof (without insulation) and the third has a conventional flat roof (with insulation). The results of performed experiments allow the evaluation of energy savings in buildings using rubber crumbs as drainage layer.

2. Materials and methods

The experimental set-up consists of three house-like cubicles (Figure 1) located in Puigverd de Lleida, Spain, with the same internal dimensions (2.4 x 2.4 x 2.4 m). Their bases consist of a mortar base of 3 x 3 m with crushed stones and reinforcing bars, and the walls present the following layers from the inside to outside; gypsum, alveolar brick (30 x 19 x 29 cm), and cement mortar as external finish layer [26,27].

The only difference between the three cubicles is the construction system of the roof (Figure 2):

- Reference cubicle: A conventional roof with 3 cm of polyurethane and finished with a single layer of gravel of 7 cm thickness.
- Puzolana cubicle: An extensive green roof with a drainage layer of 4 cm of puzolana directly below the substrate layer of 5 cm thickness.
- Rubber cubicle: An extensive green roof with a drainage layer of 4 cm of rubber crumbs directly below to the substrate layer of 5 cm thickness.

To evaluate the thermal performance of each roof system the following data were registered for each cubicle at 5 min intervals:

- Internal wall temperatures (east, west, north, south, roof and floor) and also external south wall temperature.

- Internal ambient temperature and humidity (at a height of 1.5 m).
- Heat flux at the ceiling (inside).
- Electrical consumption of the heat pump or the electric radiator.
- Solar radiation.
- External ambient temperature and humidity.

Fig. 1. Green roofs experimental cubicles in Puigverd de Lleida, Spain

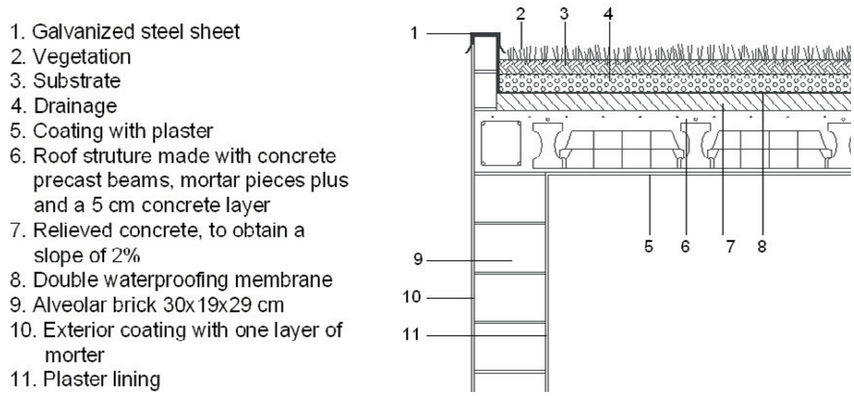

Fig. 2. Section of the constructive solution cubicles

All temperatures were measured using Pt-100 DIN B probes, calibrated with a maximum error of ±0.3 ºC. The air humidity sensors were ELEKTRONIK EE21FT6AA21 with an accuracy of ±2%. The heat flux sensors used were HUKSFLUX HFP01 with an accuracy of ±5%.

The experimental set-up offers the possibility to perform two types of tests:

- Free floating temperature, where no heating/cooling system is used. The temperature conditions in the cubicles are compared.
- Controlled temperature, where the heat pump is used in summer and an electrical oil radiator is used in winter to set the internal ambient temperature of the cubicle. The energy consumption of the cubicles is compared using different set points. To span the spectrum of results some experiments were done

using set points below the comfort range (experimental range: 16–24 ºC; comfort range: 23–26 ºC for summer and 20–24 ºC for winter).

As irrigation is essential in the summertime period in this climate, during 2011 a simple irrigation system was implemented. Also the planting of plants which are currently in a growth phase was undertaken (Figure 3).

Fig. 3. Experimental roofs with 20-25% covered by plants. Summer 2011

3. Results and discussion

The first controlled experiment was done with a set point of 24 ºC. Figure 4 shows the internal roof temperature of the studied cubicles. In the reference cubicle internal roof temperatures were around 24 ºC during all week, while in the other cubicles more fluctuations were observed. Volcanic gravel (puzolana) and rubber crumbs roofs presents similar behaviour with a slightly differences in their values.

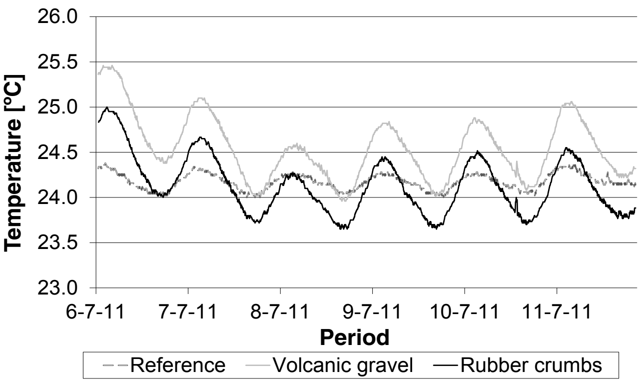

Fig. 4. Internal ceiling temperatures. Controlled experiment (set point 24 ºC)

The accumulated energy consumption of the three cubicles can be seen in Figure 5. The reference cubicle has the highest consumption followed by the rubber crumbs cubicle and finally the volcanic gravel cubicle with the lowest consumption. Compared to the reference, the cubicle with volcanic gravel had 15% less energy consumption than the one with rubber crumbs (3.6%) during this period.

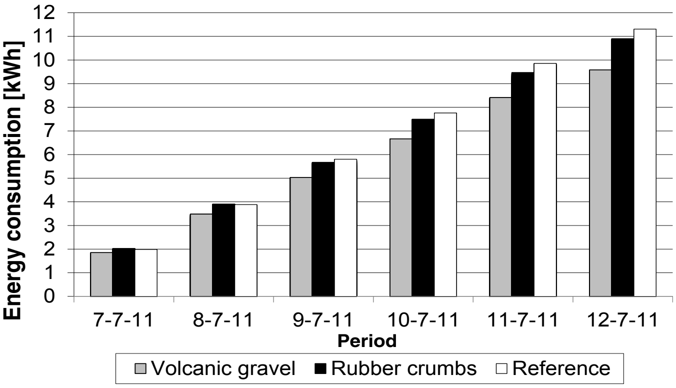

Fig. 5. Accumulated energy consumption. Controlled temperature (set point 24ºC)

In Figure 6, the internal ceiling temperatures during the controlled experiment with set point of 20 ºC can be seen. Temperatures of the volcanic gravel cubicle were higher than the other two cubicles. On the other hand, rubber crumbs and reference cubicles present similar values.

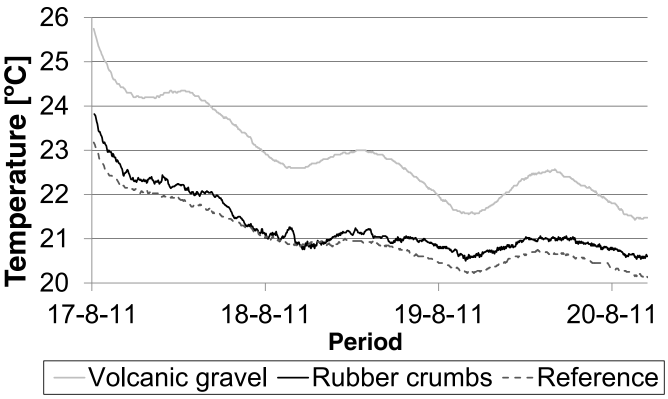

Fig. 6. Internal ceiling temperatures. Controlled experiment (set point 20 ºC)

The energy consumption when a set point of 20 ºC is kept presents a different tendency compared with set point of 24ºC (Figure 7). Volcanic gravel and rubber crumbs cubicles had almost the same consumption with a difference of 1 % between them. Moreover, green roof cubicles consumed 7 % more than the reference one.

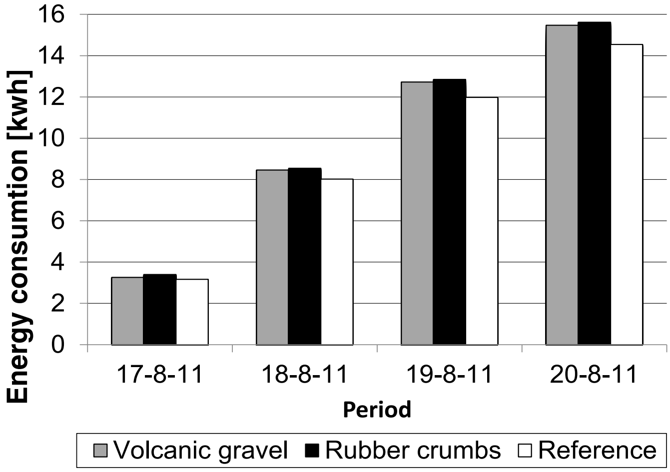

Fig. 7. Accumulated energy consumption. Controlled temperature (set point 20 ºC)

Results of internal temperatures from the free floating experiment are shown in Figure 8. An insulation effect can be seen in the internal temperatures of the rubber crumbs cubicle as it has the lowest values. Reference cubicle temperatures were 1 ºC above rubber crumbs cubicle and less than 0.5 ºC higher in the volcanic gravel cubicle.

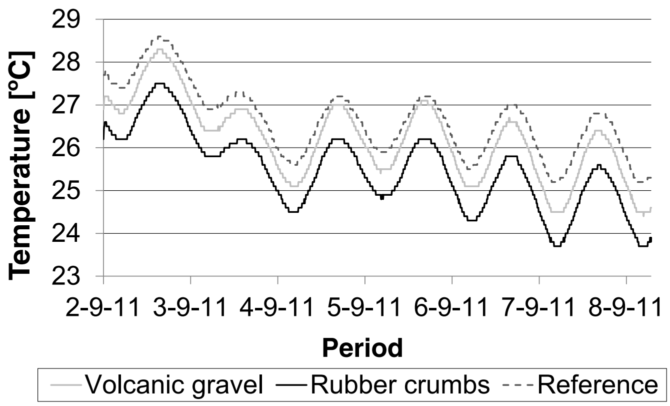

Fig. 8. Internal ambient temperatures. Free floating experiment

The internal temperature of the ceiling surfaces are presented in Figure 9. A 1 ºC difference between green roof cubicles and the reference cubicle can be observed.

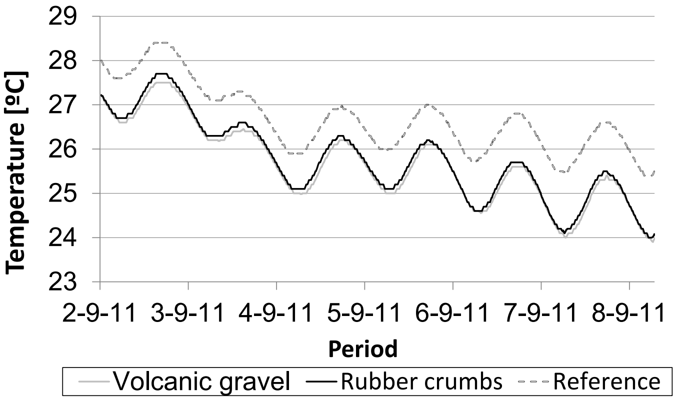

Fig. 9. Internal ceiling temperatures. Free floating experiment

Moreover, North, East and West facade temperatures were measured and present a similar behaviour, but the South facade of rubber crumbs cubicle presents a low-temperature profile compared to the other two cubicles.

4. Conclusions

After performing experiments on a Continental Mediterranean climate be concluded that:

- In the experiment with a set point of the cooling system of 24 ºC, the accumulated energy consumption of the rubber crumbs and volcanic gravel cubicles were reduced in 3,5% to 15%, respectively, comparison to the reference cubicle while maintaining comfort temperatures similar to those of the conventional roof.
- On the other hand, in the experiment with set point of 20 ºC, the accumulated energy consumption of the rubber crumbs and volcanic gravel cubicles have been 7% higher than the reference cubicle. But rubber crumbs internal ceiling cubicle temperatures maintain the same values than the reference one at 20 ºC.
- Finally an experiment was realized with free floating to check the behaviour without energy demand. Here the thermal behaviour of rubber crumbs and volcanic gravel cubicles are better than reference roof one.

Generally, extensive green roofs system has high potential to save energy during summer in Continental Mediterranean climate. Even though the experiments were done with 20% of total coverage plants, a good insulation effect was observed comparing to traditional constructive solutions (with insulation layer). These facts show the great influence of the substrate and drainage layer in the thermal behaviour of green roofs systems, and the great potential as insulation of these layers.

In addition, the use of rubber crumbs as drainage layer material in extensive green roofs has a similar behaviour as volcanic gravel roof and it's environmentally friendly.

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